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Linking Weather Variability and Economic Growth in the East African Region: A Semi-Parametric Smooth Coefficient Approach

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Abstract Unprecedented fluctuations in weather have direct and indirect effects on the East African region. This study sought to establish the association of weather variability and growth using the semi-parametric smooth coefficient approach. Findings ably reveal that weather parameters of annual average rainfall and temperature significantly influence economic growth in the region. Our results shed new light in the weather variability-economic growth nexus and suggest adoption of certain affordable yet viable policies.

Keywords Weather predictability and uncertainty; socioeconomic and political pressures; adaptation and mitigation options

1. Introduction

Globally, arid and semi-arid areas are rapidly expanding. But decreasing land resources as a consequence of erratic weather is aggravating prolonged periods of drought. Most studies suggest that there is an inextricable nexus between weather and sectors beyond agriculture, forestry and food security, tourism, health and fisheries, livestock, mining and energy [1-5]. In view of the studies that have sought to investigate the role of weather changes on agriculture in developing countries, results differ by scale and magnitude because of the model used. Nonetheless, these countries have continued to experience unpredictable rainfall that has led to acute water scarcity [6-7]. Today, unlike hitherto, African cities are facing serious water scarcity problem. A recent case is that of South Africa that is largely attributed to climate change, urbanization and uncontrolled population growth. Across the continent concerns are being raised on the availability of water resource to meet present and future needs [2]. Without policy interventions, it has been observed that productive investments and saving behaviours of the vulnerable poor will continue to be wedged [8].

Fluctuations in weather remain a thematic issue in research with divergent findings. For instance, Collier *et al.*, [9] have gleaned that instability in weather is principally engineered by the interaction of three forces namely; the equatorial climate, the West African Monsoon (WAM) winds and El Niño Southern Oscillation (ENSO). But Stephens *et al.*, [10] posit that climate change is driven by an imbalance of earths' energy forces, suggesting little possibility of anthropogenic factors, ENSO, the equatorial climate or WAM at play. As weather uncertainties continue to portend huge pressing problems in agriculture, it is projected that increased temperatures will reduce the quantity of agricultural produce. Perhaps, diversification of the crops grown and the animals kept alongside water, soil and land management practices could curb losses from wind, water and soil erosion especially where the landscape is steep and the soil dry, loose and finely granulated [11].

On an annual basis, La *Niña* has continued to place major constraints by reducing gross domestic product by about 2.7 percent across the globe [12]. A growing body of evidence reveals that the East African region will particularly experience more El Niño events and its associated negative effects [13] yet funding for small-scale, medium and large-scale climate adaptation projects is costly and only done intermittently. Current estimates indicate that about US 7.2 million dollars are directed to fund small-scale projects across the continent. Since over 90 percent of this fund is provided as grants, it necessitates African countries to continuously work with the Green Climate Fund to broaden financial flows with a bid to widen scale of mainstreaming of finances across the continent [14] and contain the extent of immeasurable losses in deaths and property through adaptation [15].

Contextual literature reveals that drought, which is more recurrent than floods, presents greater challenges to the economy than floods that are less frequent and their effects mostly localized [16-17]. In spite of the difference in scale of damage by a given disaster and estimation technique used, several lines of evidence bolster the argument that variations in weather result to severe economic outcomes [18-21]. This study aimed to demonstrate the role of weather variability on economic growth in the five East African region countries of Kenya, Uganda, Tanzania, Burundi and Rwanda, an interest that was highly motivated by the fact that only few studies have sought to demonstrate this nexus empirically.

Lorenz [22], whose arguments centred on chaos theory first draws the distinction between climate and weather by articulating that climate is different from weather in the sense that weather exhibits more deterministic patterns unlike climate whose behaviour is of indeterminate nature. The theory argues that climate is governed by a chaotic system making it extremely difficult to predict. Notwithstanding this argument, there is also a growing body of evidence that greenhouse gases such as carbon dioxide and methane are to blame for these worrying environmental changes in weather and climate [1,4].

A range of empirical investigations have concluded that weather patterns in the East African region will continue to escalate. The region will experience higher temperatures above the global mean at the end of the twenty-first century despite its dismal contribution in emissivity [15,17]. The re-greening of the African Sahel is another indicator of harsher environmental conditions that the continent will face in the near future [23]. Predicting what weather the future will present is undeniably tacit and in as much as it may not be that implicit, there is a certainty constraint of predicting outcomes [22]. This is so since future predictions are heavily dependent on the viability of the model of choice to predict the patterns of the sea surface temperatures particularly in the tropical region [24].

The neo-Malthusian theory rightly predicts that agricultural output will not meet the consumption demand of food of increased population due to environmental uncertainties, making it imperative containing the population so that its increase does not supersede food production. The theory suggests that reduced population growth rate will instrumentally combat the extent of worrisome environmental damages and promote harmony in areas that characteristically experience more frequent conflicts over water and pasture. It is also argued within the theory that colossal deforestations, poor cultivation practices and a rapidly exploding population will lead to declined natural resource base and to increased socioeconomic and political pressures [25].

Ricardian studies in the region ensconce that agricultural crops are (linearly) correlated with better revenues when technical innovations are applied but show non-linear associations with temperature and rainfall [3, 26]. Since the model cannot analyse a particular crop, models that can analyse time series, cross-section or panel data have been advocated for. For instance, Zeb [7] used a semi-parametric smooth coefficient approach which accounts for both the direct and indirect effects of climate change on economic growth in selected Nordic countries. The findings revealed an indirect yet a highly non-linear association between economic growth and climate change. This study utilises the parametric and the semi-parametric smooth coefficient approach on a production function [7, 27].

Materials and Methods

Climate change is a fairly new discipline. Estimation techniques used are equally new and only getting versatile with additional novelty in his area of research. However, the enumerative and the dynamic approaches are the commonly used estimation procedures. While the enumerative approach does not account for the intertemporal effects, in the dynamic approach, a couple of models are coalesced with climate change variables treated as exogenous factors that affect the level of output [1, 27].

The Solow-Swan, the Romer-Mankiw-Weil and the Cass-Koopmans-Ramsey models have had unrivalled applications on weighing on the influence that climate portends on economic growth prediction. Results of the models indicate that climate change spurs negative effects on economic growth. The consumption stock and

Investment are adversely affected through depreciation. This, in turn, shrinks consumption per capita. In the end, the aggregate demand and the overall level of GDP are narrowed [1, 7, 28].

The semi-parametric smooth coefficient approach provides ample ground on which climatic variables are infused to a general Cobb-Douglas function that consolidates the Solow-Swan and Romer-Mankiw-Weil growth models. This derivation begins with an ordinary Cobb-Douglas production function with two factors of Labour and Capital as shown:

$$Y_t = A_t K_t^{\beta} L_t^{1-\beta} \quad (1)$$

Where;

Y_t denotes the real aggregate income, K_t is the physical capital, L_t denotes labour and A_t, which is specified as shown in equation (*2*) represents an estimate of the total factor productivity in a given country.

$$lnA_t = \lambda Z_t \quad (2)$$

Where;

λ represents a parameter vector statistic to be measured. Z_t denotes a combination of exogenous climatic variables $\{Z_i\}$ that influence the level of productivity in a given country. The climatic variables (of temperature and rainfall) considered in this study are assumed to constitute the entire combination of the said exogenous variables that influence the level of productivity. Over time, labour is assumed to grow exponentially at a constant proportional rate n as shown;

$$L_t = Le_0^{nt} \quad (3)$$

The stock of capital of capital per unit of labour and amount of output per unit of labour are denoted as;

$$k_t = K_t / L_t \quad (4)$$

$$y_t = Y_t / L_t \quad (5)$$

Change, $(\dot{})$, in the stock of capital over time is given by;

$$\dot{kt} = \vartheta_t^k y_t - (n+\delta)k_t = \vartheta_t^k k_t^{\alpha} - (n+\delta)k_t \quad (6)$$

It follows that ϑ_t^k is the share of productivity that is invested in a distinct period t and δ is the rate of (physical capital) 'wear and tear' or equivalently, depreciation.

The steady state expression of the capital state is given by;

$$k_t^* = [\vartheta_t^k / (n+\delta)]^{1/(1-\beta)} \quad (7)$$

By utilizing the mathematical laws of indices and substituting k_t^* in equation (*7*) to equation (*1*) and consequently taking the natural logarithms in both sides, a condensed form of the Solow-Swan growth model (of 1956) is generated as shown;

$$lny_t = \omega_0 + \omega_1\{z_{it}\} + \frac{\beta}{1-\beta} ln\vartheta_t^k - \frac{\beta}{1-\beta} \ln(n+\delta) \quad (8)$$

Where;

ω_0 represents the intercept. z_{it} represents the exogenously determined climatic factors that renders the production function to be semi-parametric and in whose absence the model becomes a standard parametric model with inability to weigh both the direct and the indirect effects of the factors on economic growth.

In 1992, Mankiw, Weil and Romer [29] added human capital as an additional factor determining production. From their innovation, the production function was re-defined as;

$$Y_t = A_t K_t^{\beta} H_t^{\alpha} L_t^{1-\beta-\alpha} \quad (9)$$

Where;

H_t is the stock of human capital; the stock of physical and human capital, and level of output per worker are given as;

$$k_t = K_t / H_t \quad (10)$$

$$h_t = H_t / L_t \quad (11)$$

$$y_t = Y_t / L_t \quad (12)$$

It is assumed that any form of capital depreciates at a rate δ with population growing at a constant rate n. Utilising the laws of indices we have natural logarithms taken on both sides, giving the Weil-Mankiw-Romer model as;

$$lny_t = \omega_0 + \omega_1\{z_{it}\} + \frac{\beta}{1-\beta-\alpha} ln\vartheta_t^k + \frac{\alpha}{1-\beta-\alpha} ln\vartheta_t^h - \frac{\beta+\alpha}{1-\beta-\alpha} ln(n+\delta) \quad (13)$$

We ably apply equations (*8*) and (*13*) in the empirical specification to generate condensed forms of the Solow model in equation (*14*) and condensed Weil-Mankiw-Romer model in equation (*15*) as shown;

$$lny_t = \beta_0 C_i + \beta_1 C_t + \beta_2 lnk_{it} + \beta_3 lnpopr_{it} + \beta_4 x_{it} + \beta_5 g_{it} + \mu_t \qquad (14)$$

$$lny_t = \alpha_0 C_i + \alpha_1 C_t + \alpha_2 lnk_{it} + \alpha_3 lnpopr_{it} + \alpha_4 lnh_{it} + \alpha_5 x_{it} + \alpha_6 g_{it} + \varepsilon_t \qquad (15)$$

But; x and $g \in Z$

Where;

$C_i$and C_t represent the country and time specific dummies, in that order. Verily, y represents the real GDP per capita. k represents the gross fixed capital formation as a share of GDP. h is the gross secondary school enrolment rate, $popr$ is the population growth rate, x is the maximum annual temperature (recorded in a given month). g is the total annual rainfall. As articulated, is assumed that temperature and rainfall constitute an entire set of climate estimates that influence growth. μ and ε are the disturbance terms, or equivalently, white noise.

Motivation for choice of variables was guided by literature, which suggests that the East African region has continued to experience sharp escalations in both temperature and rainfall with periods of *El Niño* immediately followed by *La Niña* [30-33].

This study utilises cross-sectional data from the World Development Indicators (WDI) and the World Bank's Climate Change portal to determine what influence weather variability portends on economic growth in the East African countries of Rwanda, Burundi, Uganda, Tanzania and Kenya. Data sources for variables under consideration and their notations is shown in Table 1. The parametric and the semi-parametric panel fixed effects models are used in the analysis.

Table 1: Data sources

Variable	Notation	Measurement	Expected Sign	Source
Real GDP per capita	y	Real GDP per capita annual series	Dependent variable	WDI
Real gross fixed capital formation	k	As proportion of annual GDP series	Negative	WDI
Gross secondary school enrolment rate	hnc	Annual secondary school enrolment series	Positive	WDI
Population growth rate	pop	Annual population growth rate series	Negative	WDI
Average rainfall	rn	Milliliters	positive	WB climate change Portal
Average temperature	tmp	Degrees Celsius (°C)	Negative	WB climate change portal

The econometrics approach of the study draws its foundations in the stochastic frontier framework, which places emphasis on the exogenous contribution of (a set of) environmental factors that has propensity to influence economic performance of an economy. The framework combines both the parametric and the non-parametric approaches. The framework is used when the functional form of the regressors is non-linear or partially non-linear. The study utilized a generalized dynamic coeffient models that utilize the customized polynomial linear regression plus the Nadaraya-Watson constant Kernal with an ultimate aim of measuring the slope coefficients $\alpha_1(\cdot)$ and $\beta_1(\cdot)$.

The equation used is decomposed into two distinct parts within the model. This set of environmental factors is assumed to influence the level of productivity in a production function framework where, the intercept and the slope coefficients $\alpha_1(\cdot)$ and $\beta_1(\cdot)$ are the unknown functions of the exogenous factors. The stochastic frontier model is defined as;

$$y_i = \alpha(z_i) + X_i^{\prime}\alpha(z_i) + v_i - \mu_i \qquad (16)$$

Where;

v_i is the normal white noise term and is independently and identically distributed; or equivalently, $v_i \sim iidN(0, \sigma_v^2)$ and μ_i, is the half-normal technical inefficiency term; or equivalently, $\mu_i = \mu(z_i; \sigma)$.

$\{v_i - \mu_i\}$ is the composite error term.

We note that without the inclusion of the environmental factors; or equivalently, climatic factors, the model is termed as a standard parametric stochastic frontier model. We also note that in order to weigh the relevance of the climatic factors, p values are used to determine their relevance, say, on a given level of significance.

Results and Discussion

Variables under consideration and their descriptive statistics is as provided in Table 2. In Table 3, estimated results for the parametric and the semi-parametric model with annual average temperature and annual average rainfall determined exogenously. The parametric and semi-parametric outputs are presented in column 2 and column 3 of Table 3, respectively.

Table 2: Descriptive statistics of variables

Variable Notation	Mean	Min	Max
lny	-1.527843	-1.860827	3.56173
lnk	2.187274	-0.9669842	5.048477
$lnhnc$	2.376838	0.3477159	4.057739
$lnpop$	1.059414	-1.296092	2.069125
tmp	22.06564	18.7907	18.7907
rn	90.49564	37.3523	133.019

Table 3: Estimates for the parametric and the semi-parametric model with average temperature and average rainfall determined exogenously

Variable	Parametric Model	Semi-Parametric Model
Constant	-2914.2***	4.77e-27***
	(12.19)	(5.52e-28)
lnk	0.164***	0.222*
	(0.00203)	(0.0961)
$lnhnc$	-1.956***	-2.293***
	(0.00768)	(0.287)
$lnpop$	0.507***	0.419
	(0.00644)	(0.311)
tmp	0.0146***	0.0337
	(0.00299)	(0.132)
rn	-0.0254***	-0.0331***
	(0.000211)	(0.0101)
Country dummies	Yes	Yes
Year dummies	Yes	Yes

Cluster-robust standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

It is gleaned through these results for the parametric model that the effect of a unit percentage increase in the real gross capital formation leads to 16% increment in the real GDP per capita but a 1% increase in the gross secondary school enrolment rate leads to 19.56% decline in the real GDP per capita. A 1% increase in population growth rate leads to a 5% increase in real GDP per capita. Findings for the annual average temperature and the annual average annual rainfall, which are exogenously determined, indicate that a unit percentage increase in both variables lead to 1.5% increase and 2.5% decrease in the real GDP per capita, respectively. It is important noting that for all variables under consideration in the parametric model, the estimates are statistically significant at 1% levels and have a positive sign but the gross secondary school enrolment rate and the annual average rainfall that have a negative sign.

Results for the semi-parametric model reveal that only the real gross capital formation is statistically significant at 90% confidence interval, has a positive sign and that a unit increase in the parameter leads to over 22% increase in the real GDP per capita. The gross secondary school enrolment rate and the annual average rainfall lead to a decrease in the real GDP per capita by 22.9% and 3.3%, respectively and are significant at 99% confidence interval. Results for the population growth rate and the annual average temperature are statistically insignificant.

Conclusion

This study attempts to unravel the link between weather variability and economic growth across the East African region using the semi-parametric smooth coefficient approach. In the region, this is not the first study to analyse the interplay between economic growth and climate variability but it is probably the first to utilize the both the parametric and the semi-parametric panel fixed effects approaches.

Data used encompasses the five East African countries of Kenya, Uganda, Tanzania, Rwanda and Burundi spanning the period 1964 – 2014. There are important policy issues that can be deduced from these results. Since empirical literature suggests that agriculture is a driving sector in the region yet it is weather sensitive, improving weather forecast technologies, embracing technical innovations for small-scale farmers through the adoption and scaling up of precision agriculture by use of drones, irrigation and continued research and development on hybrid seed varieties is important. More importantly is investigating on suitability of soils for diversification of crops and improving storage facilities once the farm produce is harvested in order to ensure food security for the growing population.

Future studies should investigate the welfare effects and estimate country level impacts of weather variability in the region. Equally important is recognizing and encouraging the role of government, private sector, Non-Governmental Organizations and other development partners have a role to play in steering affordable and viable adaptation options through subsidies.

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